CALIFORNIA DIVISION OF MINES AND GEOLOGY

FAULT EVALUATION REPORT FER-193

NORTHERN DEATH VALLEY - FURNACE CREEK FAULT ZONE

SOUTHERN MONO AND EASTERN INYO COUNTIES, CALIFORNIA

by

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INTRODUCTION

Potentially active faults in southern Mono and eastern Inyo Counties that are evaluated in this Fault Evaluation Report (FER) are collectively referred to as the Northern Death Valley - Furnace Creek fault zone (NDVFC) (Figure 1). The Fish Lake Valley - Northern Death Valley study area is located in the Mt. Barcroft, Piper Peak, Soldier Pass, Magruder Mtn., Last Chance Range, Ubehebe Crater, Tin Mtn., Grapevine Peak, Stovepipe Wells, and Chloride Cliff 15-minute quadrangles (Figure 1). These faults are evaluated as part of a statewide effort to evaluate faults for recency of activity. Those faults determined to be sufficiently active and well-defined are zoned by the State Geologist as directed by the Alquist-Priolo Special Studies Zones Act of 1972 (Hart, 1985).

SUMMARY OF AVAILABLE DATA

The Fish Lake Valley - Northern Death Valley study area is located in the western Basin and Range geomorphic province and is characterized by oblique Basin and Range extensional tectonics. This tectonic style results in both normal and right-lateral faulting.

Topography in the study area ranges from flat playa surfaces in the southern part of the study area to areas of locally rugged relief in the Cucomungo Canyon - Last Chance Canyon area in the Magruder Mountain quadrangle (Figure 1). Elevations in the study area range from about 1830 meters above to about 80 meters below sea level. Precipitation is very sparse and is as little as 4 cm/year in Death Valley. Development in the study area is extremely low and much of the study area lies within Death Valley National Monument. However, much of the NDVFC fault zone follows paved access roads.

Rock types in the study area include pre-Cambrian and Paleozoic metasedimentary and sedimentary rocks, Mesozoic plutonic rocks, Tertiary sedimentary and volcanic rocks, and late Quaternary alluvium, eolian, and lacustrine deposits (Denny, 1965; Hunt and Mabey, 1966; McKee and Nelson, 1967; Strand, 1967; Reynolds, 1969; Krauskopf, 1971; Streitz and Stinson, 1974; Stewart and others, 1974; Jennings, 1977; McKee, 1985; Moring, 1986).

The NDVFC fault zone is a major right-lateral strike-slip fault zone that extends from near the National Park Services headquarters northwest for about 160 km into Fish Lake Valley (Figure 1). Curry (1938) first mapped the NDVFC fault zone and recognized that there was a significant right-lateral strike-slip component, based on the geomorphic expression of the fault. Cumulative strike-slip displacement along the NDVFC fault zone has been reported from 40 km to 100 km (Stewart, 1967, 1983; Stewart and others, 1968). This contrasts with smaller magnitudes of displacement along the southern Death Valley fault zone, which was originally reported to be no greater than 8 km (Wright and Troxel, 1967) and is now reported to be about 35 km (Butler and others, 1988) In order to resolve the discrepancy in displacement values, Stewart (1983) proposed that movement along the NDVFC fault zone commenced prior to the onset of displacement along the southern Death Valley fault zone. This explains the difference in magnitudes of displacement and the formation of the pull-apart basin in central Death Valley (Burchfiel and Stewart, 1966). Slip-rates for the NDVFC fault zone have not been reported.

Mapping of the NDVFC fault zone that will be evaluated in this FER includes Brogan (1979), Krauskopf (1971), Stewart and others (1974), McKee and Nelson (1967), McKee (1985), Moring (1986), Reynolds (1969), and Hunt and Mabey (1966). The NDVFC fault zone will be discussed from north to south.

FISH LAKE VALLEY

The NDVFC fault zone in the Fish Lake Valley area is characterized by normal oblique-slip displacement (Figures 2a, 2b). The magnitude of displacement is not known, nor are the normal and strike-slip components of displacement. The NDVFC fault zone continues northwest into Nevada (outside of this study area). Studies have documented evidence of late Holocene displacement along the NDVFC fault zone in Nevada (Sawyer and Slemmons, 1988). Sawyer and Slemmons reported that facies and thickness changes of late Holocene alluvial units across the fault indicated a dominant lateral component of displacement, although magnitudes of displacement are not yet known.

The NDVFC fault zone in the Fish Lake Valley part of the study area has been mapped by Brogan (1979), Krauskopf (1971), Stewart and others (1974), and McKee and Nelson (1967) (Figures 2a, 2b).

Krauskopf (1971) mapped north to northwest-trending traces of the NDVFC fault zone in the Mt. Barcroft 15-minute quadrangle (shown in purple, Figure 2a). Strands of the NDVFC fault zone mapped by Krauskopf juxtapose or offset Quaternary alluvium against Holocene alluvium and, locally, offset Holocene alluvium (locality 1, Figure 2a). The style of faulting along strands of the NDVFC fault zone in the Mt. Barcroft quadrangle is not indicated by Krauskopf. However, the prominent east-facing scarps in alluvium indicate a significant component of down-to-the-east normal displacement.

Stewart and others (1974) mapped traces of the NDVFC fault zone in the Piper Peak 15-minute quadrangle (shown in blue, Figure 2a). Traces mapped by Stewart and others are generalized and juxtapose younger alluvium against older alluvium except at locality 2 where younger alluvium is offset (Figure 2a). Stewart and others did not differentiate between Pleistocene and Holocene alluvium. However, it is assumed that their Qf unit (alluvial fan deposit) is latest Pleistocene to Holocene in age. A western trace of the NDVFC fault zone mapped by Stewart and others offsets bedrock against older alluvium (Figure 2a).

McKee and Nelson (1967) mapped traces of the NDVFC fault zone in the Soldier Pass 15-minute quadrangle (shown in blue-green, Figure 2b). Two northwest-trending zones of discontinuous, generally down-to-the-east faults extend to Cottonwood Creek where a single fault zone continues southeast along the east side of Fish Lake Valley (Figure 2b). Southeast of locality 3 (Figure 2b), west-facing scarps in alluvium were mapped by McKee and Nelson that trend toward the Willow Wash area. McKee and Nelson, like Stewart and others (1974), did not differentiate between Pleistocene and Holocene alluvium. It is assumed that McKee and Nelson's Qf unit is latest Pleistocene to Holocene in age. Locally faults mapped by McKee and Nelson offset this younger alluvial deposit, such as at localities 3 and 4 (Figure 2b).

Brogan (1979) mapped late Quaternary faults along the entire extent of the NDVFC fault zone, based on air photo interpretation of low-sun-angle photographs and field mapping, at a scale of 1:24,000 (plotted at 1:62,500 in this FER). The quality of Brogan's mapping is very good and provides documentation of latest Pleistocene and Holocene surface faulting along much of the NDVFC fault zone. Brogan estimated the ages of geomorphic surfaces offset by and concealing strands of the NDVFC fault zone, based on preservation of constructional surfaces, rock varnish, desert pavement, and relative positions above active channels. The estimated ages of the geomorphic surfaces are presented in Table 1.

Faults mapped by Brogan in the Mt. Barcroft quadrangle (shown in black) agree in general with the mapping of Krauskopf (1971), although differences in detail exist (Figure 2a). Specifically Brogan has mapped faults in considerably more detail, such as near the mouth of Wildhorse Creek and Furnace Creek and at locality 5 (Figure 2a). Brogan (p.c., March 1988) reported that several small drainages were right-laterally offset near the linear ridge at Wildhorse EM (southeast of locality 1, Figure 2a),

indicating that a component of right-lateral strike-slip displacement characterizes the NDVFC fault zone in the southern Fish Lake Valley region. Locally, strands of the NDVFC fault zone offset Brogan's unit Q1b (Figure 2a).

Faults mapped by Brogan and Stewart and others (1974) agree reasonably well with respect to location of major branches, although differences in detail exist (Figure 2a). Brogan mapped a zone of discontinuous, generally east-facing scarps juxtaposing bedrock against older alluvium west of the principal faults mapped by Stewart and others (Figure 2a).

Brogan mapped faults along the west side of Fish Lake Valley and southeast of locality 3 that generally correspond with faults mapped by McKee and Nelson (1967) (Figure 2b). A significant zone of tonal lineaments and low scarps in unit Q1A was mapped by Brogan northwest of locality 3 and east of faults mapped by McKee and Nelson (Figure 2b). Brogan (p.c., March 1988) stated that some of these lineaments could be artificial. Mining activity during the previous century in the Fish Lake Valley region resulted in many roads or paths that currently may be manifested as tonal lineaments. However, Brogan concluded that most of these features are probably due to late Holocene faulting or fissuring, based on the overall trend of the lineaments and their association with well-defined faults to the northwest.

Two trenches were excavated by T. Sawyer, University of Nevada, Reno graduate student, across this eastern branch of the NDVFC fault zone mapped by Brogan in southern Fish Lake Valley (localities 6 and 7, Figure 2b). The northern trench (T-4) did not have clear evidence of faulting in late Holocene playa deposits, although numerous fractures were observed in the trench (locality 6, Figures 2b, 5). Trench T-3 also exposed fractures in late Holocene alluvial and playa deposits and a probable fault was located at station 13 (locality 7, Figures 2b, 4). A thin, massive sand bed (unit 3) is displaced (warped) about 30 cm over a distance of about 1 1/2 meters (T. Sawyer, p.c., April 1988) (Figure 4). Multiple rupture events along this probable fault are indicated by offsets of overlying units 2 and 1 of 10 cm and about 2 cm, respectively (Figure 4). The apparent vertical sense of displacement is consistently down to the east. Though some of the features mapped by Brogan along the eastern zone may be artificial, trench T-3 indicates that the more prominent features along this northwest trend are probably tectonic.

WILLOW WASH - LAST CHANCE CANYON

The trend of the NDVFC fault zone changes to a more westerly trend in the Willow Wash and Cucomungo Canyon areas, which suggests a compressional component of displacement, and is consistent with a left step between two segments of a right-lateral strike-slip fault zone.

Faults in the Willow Wash - Last Chance Canyon area were mapped by McKee and Nelson (1967), Brogan (1979), McKee (1985), Moring (1986) (Figure 2b).

McKee and Nelson (1967) mapped a broad zone of faults, that trend both northwest and northeast that offset bedrock in the Willow Wash area (shown in blue-green, Figure 2b). Brogan (1979) (shown in black) mapped a broad zone of short, discontinuous faults in the Willow Wash area that only locally correspond to faults mapped by McKee and Nelson (Figure 2b). Several bedrock scarps in the Willow Wash area are capped by alluvium, suggesting Quaternary deformation (vertical) (Brogan, p.c. March 1988).

McKee (1985) mapped traces of the NDVFC fault zone in the Magruder Mtn. 15-minute quadrangle (shown in olive-green, Figure 2b). The NDVFC fault zone is mapped by McKee as a right-lateral strike-slip fault delineated by a single trace throughout much of the Magruder Mtn. quadrangle, but splays into two traces at locality 8 (Figure 2b). McKee, like McKee and Nelson (1967), did not differentiate between Pleistocene and Holocene alluvial deposits, although his Qa alluvial unit is assumed to be late Pleistocene to Holocene in age. The NDVFC fault zone mapped by McKee offsets Quaternary alluvium against bedrock and locally juxtaposes late Pleistocene to Holocene alluvium against Quaternary alluvium at locality 9 (Figure 2b).

Mapping by Brogan (1979) generally corresponds with mapping by McKee to within about 1 1/2 km north of locality 8 (Figure 2b). However, considerable differences in detail exist, especially south of Willow Spring where McKee mapped the principal trace of the NDVFC fault as much as 300 m to the southwest (Figure 2b). Brogan reported that unit Q1B is right-laterally offset about 1.2m at locality 30 (Figure 2b). The NDVFC fault zone mapped by Brogan southeast of locality 8 is very discontinuous and only locally corresponds with traces mapped by McKee (Figure 2b).

Faults mapped by Moring (1986) (shown in red, Figure 2b) generally correspond with traces mapped by Brogan northwest of locality 8 and with traces mapped by McKee southeast of locality 8, although differences in detail exist (Figure 2b). The single trace mapped by Moring northwest of locality 8 is inferred from aerial photography. The eastern trace of the NDVFC fault zone mapped by Moring at the south end of the Magruder Mtn. quadrangle juxtaposes late Pleistocene alluvium against Holocene alluvium (locality 10, Figure 2b). This trace was partly mapped by Brogan, who mapped the southern end of the fault concealed by alluvium (Figure 2b).

NORTHERN DEATH VALLEY

The NDVFC fault zone in the Northern Death Valley area is characterized by a northwest-trending zone of right-lateral strike-slip faults with local, predominantly north to north northwest-trending minor normal faults (Figures 2c-2e). Cumulative right-lateral strike-slip displacement has been estimated to be 40 to 100 km, based on apparent offsets of stratigraphic trends of upper Precambrian and Paleozoic rocks (Stewart, 1967, 1983). The NDVFC fault zone in the Northern Death Valley area has been mapped by Moring (1986), Reynolds (1969), Hunt and Mabey (1966), and Brogan (1979) (Figures 2c-2e).

Moring (1986) mapped traces of the NDVFC fault zone (his Furnace Creek fault zone) in the Last Chance Range and Ubehebe Crater 15-quadrangles and stated that the fault zone is characterized by predominantly right-lateral strike-slip displacement (Figure 2c). Moring specifically mapped the surficial geology in these quadrangles and has mapped alluvial fan units in detail. The principal trace of the NDVFC fault zone in the Last Chance Range quadrangle is concealed by Holocene alluvium of Oriental Wash (Figure 2c). Two very short fault traces that offset late Pleistocene alluvium at locality 11 are on trend with a dissected linear ridge in Tertiary bedrock to the northwest and well-defined traces in the Ubehebe Crater quadrangle to the southeast, suggesting the location of the principal trace in the Holocene alluvium (Figure 2c). Moring mapped an extremely broad, north northwest-trending zone of very discontinuous normal faults northeast of the principal trace of the NDVFC fault zone in both the Last Chance Range and Ubehebe quadrangles (Figure 2c). These faults offset late Pleistocene alluvium, but generally are concealed by Holocene alluvium, except at locality 12, where Moring mapped Holocene alluvium as offset (Figure 2c).

In the Ubehebe Crater quadrangle the NDVFC fault zone is mapped by Moring as offsetting latest Pleistocene alluvium and Holocene alluvium is juxtaposed against Pleistocene alluvium (Figure 2c). Moring stated that no geomorphic surfaces younger than his late Pleistocene alluvial fan unit Qf2c could be shown to be offset along the NDVFC fault zone. Moring's Qf2c alluvial fan unit is characterized by "moderately paved surfaces slightly dissected by braided to subparallel channels as much as 2 m deep".

Reynolds (1969) mapped a northwest-trending linear fault zone in the Grapevine Peak 15-minute quadrangle (shown in yellow, Figure 2d). The NDVFC fault zone mapped by Reynolds offsets Holocene alluvium and playa deposits of northern Mesquite Flat (Figure 2d). Reynolds reported that in the vicinity of the Death Valley highway the fault is delineated by a scarp in late Pleistocene and Recent (Holocene) alluvium that ranges in height from 0.6 to 1.5 m (locality 13, Figure 2d). The NDVFC fault in the playa deposits of northern Mesquite Flat is delineated by "a furrowed ridge and scarps" (Reynolds, 1969, Figure 2d). Reynolds (1969) stated that, based on the offset of alluvial gravels and playa deposits, the NDVFC fault zone in the Grapevine Peak quadrangle "has been active in late Recent (Holocene) time". Reynolds stated that the NDVFC fault zone has a significant right-lateral strike-slip component, based on right-laterally deflected drainages and right-laterally offset alluvial fan margins. Locally, Reynolds reported that Pleistocene alluvial fan deposits are offset 46 meters right-laterally (locality 14, Figure 2d). Reynolds did not know what the cumulative strike-slip displacement was along the NDVFC fault zone.

Hunt and Mabey (1966) mapped traces of the NDVFC fault zone in the Stovepipe Wells and Chloride Cliff 15-minute quadrangles (shown in brown, Figure 2e). The principal trace of the NDVFC fault zone is largely mapped as concealed by Holocene alluvium (Figure 2e). Locally, Hunt and Mabey mapped Holocene alluvium as offset by the NDVFC fault zone (locality 15, Figure 2e). Near the southern boundary of the Chloride Cliff quadrangle the NDVFC fault zone trends more northerly and is delineated by several short normal faults that offset Holocene alluvium (Hunt and Mabey, Figure

2e). Hunt and Mabey mapped a branch fault west of the principal trace of the NDVFC that is entirely concealed by Holocene alluvium and, locally, by Tertiary lacustrine deposits (locality 16, Figure 2e).

Hunt and Mabey mapped several north-trending faults east of the principal trace of the NDVFC fault zone in the Stovepipe Wells quadrangle (east of locality 15, Figure 2e). These branch faults locally offset late Pleistocene alluvium but are concealed by Holocene alluvium (Figure 2e).

Brogan (1979) mapped traces of the NDVFC fault zone in the Northern Death Valley area that are generally characterized by a relatively narrow, linear, northwest-trending zone right-lateral strike-slip faults (Figures 2c-2e). Brogan mapped a very discontinuous and distributive pattern of faulting in most of the Last Chance Range quadrangle (Figure 2c). The location of the principal trace of the NDVFC fault zone is suggested by the dissected linear ridge in Tertiary bedrock and the short fault trace at Little Sand Spring, but there is no through-going fault zone at the surface (Figure 2c). Brogan also mapped a broad zone of discontinuous faults east of the principal trace of the NDVFC fault zone (Figure 2c). However, there is little agreement with respect to fault location between Brogan and Moring (1986) along this broad north northwest-trending zone (Figure 2c).

The principal trace of the NDVFC fault zone mapped by Brogan in the Ubehebe Crater quadrangle is similar to the fault zone mapped by Moring (1986), although considerable differences in detail exist (e.g. localities 17-19, Figure 2c). Brogan reported that the principal trace of the NDVFC fault zone is delineated by geomorphic features indictive of youthful strike-slip faulting, such as diverted and displaced channels, ponded alluvium, sags, and scarps in alluvium (Figure 2c). The fault locally offsets unit Q1C, which is estimated to be early Holocene (Table 1).

Brogan mapped a generally northwest-trending zone of discontinuous faults in the Death Valley Wash area (Figure 2c). Although this zone of faults was not mapped by Moring, the traces generally offset Tertiary and Pleistocene lacustrine deposits mapped by Moring. This zone of faulting continues southeast onto the Tin Mountain quadrangle (Figures 2c and 2d).

The linear northwest-trending NDVFC fault zone mapped by Brogan continues southeast onto the Tin Mountain and Grapevine Peak 15-minute quadrangles (Figure 2d). The NDVFC fault zone in the Tin Mountain quadrangle is fairly continuous except for an approximately 2 km segment southeast of locality 20 and an approximately 5 km segment concealed by alluvium southeast of locality 14 (Figure 2d). Brogan mapped discontinuous, minor normal faults along the base of the east side of the Panamint Range (Figure 2d - not plotted). These minor normal faults will not be evaluated in this FER because they are located in a relatively remote part of the study area and air photo coverage is not complete.

Mapping by Brogan generally corresponds to mapping by Reynolds (1969) in the Grapevine Peak quadrangle, although Brogan mapped the fault in considerably more detail (Figure 2d). Brogan reported that drainage channels developed in early Holocene unit Q1C are systemmatically displaced

0.8-1.2m right-laterally along well-defined strands of the NDVFC fault zone about 3 1/2 km northwest of locality 13 (Figure 2d). At and southeast of locality 13 faults mapped by Brogan are located as much as 150 meters west of the single fault trace mapped by Reynolds (Figure 2d).

Brogan mapped the NDVFC fault zone in the Stovepipe Wells and Chloride Cliff quadrangles that only locally corresponds with faults mapped by Hunt and Mabey (1966) (Figure 2e). Brogan mapped traces of the NDVFC fault zone in the Mesquite Flat area of the Stovepipe Wells quadrangle that offset playa deposits considered by Brogan to correlate with his Holocene Q1b unit (Figure 2e). The principal trace of the NDVFC fault zone mapped by Brogan is delineated predominantly by well-defined southwest-facing scarps in alluvial units Q1B and Q1C and Tertiary lacustrine deposits northwest of Beatty Junction (Figure 2e).

Southeast of Beatty Junction Brogan mapped the NDVFC fault zone as concealed by Holocene alluvium (Figure 2e). Several short, discontinuous, generally north-trending normal faults mapped by Brogan offset Holocene alluvium and playa deposits reported to be about 2 ka by Hunt and Mabey near Salt Springs and the National Park Service headquarters (Figure 2e). Faults mapped by Brogan in the southern part of the Chloride Cliff quadrangle, which only locally correspond to faults mapped by Hunt and Mabey (1966), are delineated by generally west-facing scarps in alluvium (Figure 2e). This southern end of the NDVFC fault zone marks the transition from predominantly strike-slip displacement to predominantly normal displacement.

INTERPRETATION OF AERIAL PHOTOGRAPHS AND FIELD OBSERVATIONS

Aerial photographic interpretation by this writer of faults in the Fish Lake Valley - Northern Death Valley study area was accomplished using U.S. Geological Survey (GS-VFDT, 1982, scale varies from 1:24,000 to 1:30,000), U.S. Bureau of Land Management (C-M000, 1975, scale 1:20,000), and University of Nevada, Reno (FLV, 1968 and 1970, scale 1:12,000) air photos.

Approximately 6 days were spent in the study area in January and February 1988 by this writer. Selected fault traces were field checked and subtle features not observable on the aerial photographs were mapped in the field. Trenches in Fish Lake Valley excavated by T. Sawyer were briefly examined in January by this writer. Results of aerial photographic interpretation and field observations by this writer are summarized on Figures 3a-3e.

Late Quaternary slip-rates have not previously been reported for the NDVFC fault zone. One area that could yield slip-rate data was reported by Reynolds (1969) at locality 14 (Figure 2d). The margin of a remnant late Pleistocene alluvial fan is offset about 46 meters right-laterally. The age of the incision of the fan margin is not known, but it is assumed to be about 20 ka, based on the possible early Holocene age of younger alluvial fans that partly conceal the margin of the older fan and occur as terraces upstream from the offset margin. If the stream incision occurred about 20 ka and the 46 meters of displacement occurred after the stream incision, a

slip-rate of 2.3 mm/yr can be inferred. This slip-rate represents a crude estimate at best, because it is not known how much of the apparent right-lateral displacement is due to erosion or how much of the offset fan margin was removed by subsequent erosion. Also, the incision of the fan margin is probably episodic, so a piercing point can only be approximated.

FISH LAKE VALLEY

The NDVFC fault zone in Fish Lake Valley is a complex northwest-trending zone of predominantly normal (east side down) faults with, locally, a significant component of right-lateral strike-slip displacement (Figures 3a and 3b).

The NDVFC fault zone in the Mt. Barcroft and Piper quadrangles is moderately well to well-defined and is delineated by geomorphic evidence of latest Pleistocene to Holocene right-lateral oblique-slip (normal) displacement, such as prominent scarps in late Pleistocene and Holocene alluvium, sidehill benches, closed depressions, right-laterally deflected drainages, and linear ridges in alluvium (Figure 3a). Scarps in late Pleistocene alluvium along the west side of Fish Lake Valley south of sec. 7, T5S, R37E in the Piper Peak quadrangle are characteristic of predominantly east-side down normal displacement (Figure 3a).

Faults mapped by Brogan (1979) and Krauskopf (1971) in the Mt. Barcroft quadrangle were generally verified by this writer, although differences in detail exist (Figures 2a, 3a). Specifically, well-defined geomorphic features indicative of latest Pleistocene to Holocene displacement were not observed in the Toler Creek area and in sec. 35, T3S, R35E where the fault is delineated by a poorly defined linear escarpment (Figures 2a, 3a). Numerous branch faults mapped by Brogan in the NE 1/4 of sec. 19, T4S, R36E were not verified (Figures 2a, 3a).

Faults mapped by Brogan (1979) in the Piper Peak quadrangle generally were verified by this writer, although minor differences in detail exist (Figures 2a, 3a). Faults mapped by Brogan west of the principal trace of the NDVFC fault zone were partly verified, especially southeast of locality 21 (Figures 2a, 3a). Northwest of locality 21, faults mapped by Brogan are moderately to poorly defined and were not verified.

Traces of the NDVFC fault zone in the Soldier Pass quadrangle range from moderately to poorly defined along parts of the southwestern side of Fish Lake Valley to well-defined in areas of the valley floor (Figure 3b). Mapping by McKee and Nelson (1967) and Brogan (1979) was generally verified by this writer, although differences in detail exist (Figures 2b, 3b). The western-most branch of the NDVFC fault zone is moderately defined and, except for local tonal lineaments in late Pleistocene to Holocene alluvium, doesn't have geomorphic evidence of latest Pleistocene to Holocene displacement (locality 22, Figure 3b). The western branch of the NDVFC fault zone southeast of sec. 3, T6S, R37E is generally moderately to poorly defined and does not have geomorphic evidence of latest Pleistocene to Holocene displacement (Figures 2b, 3b).

There is fairly good agreement between mapping by Brogan and this writer along traces of the eastern branch of the NDVFC fault zone in the floor of southern Fish Lake Valley. Geomorphic evidence of Holocene displacement includes scarps in Holocene alluvium, a linear ridge, linear troughs, and well-defined tonal lineaments (localities 23-25, Figure 3b). The alluvium in this area consists of fluvial and lacustrine deposits with local veneers of eolian sand. Soil development, based on trench exposures (Figures 4 and 5), is very weak, indicating a very young geomorphic surface. The shallow trough at locality 25 (Figure 3b) suggests that surface or near surface displacement (faulting or fissuring) has probably occurred during mid to late Holocene time. The style of displacement along this eastern zone is not completely understood. Possible right-laterally deflected drainages, the generally linear trend of the features, and the lack of significant scarps all indicate a predominantly right-lateral strike-slip style of displacement (Figure 3b).

Mapping by Brogan southeast of locality 3 was generally verified by this writer (Figures 2b, 3b). This branch of the NDVFC fault zone in southern Fish Lake Valley is moderately defined and has geomorphic evidence suggesting latest Pleistocene to Holocene right-lateral strike-slip displacement, such as a linear ridge, right-laterally deflected drainages and a right-laterally deflected ridge in Pleistocene alluvium (Figure 3b). Southeast of sec. 29, T6S, R37E the fault is generally poorly defined by a dissected linear escarpment in Pleistocene and Tertiary deposits (Figure 3b).

WILLOW WASH - LAST CHANCE CANYON

The NDVFC fault zone in the Willow Wash area is generally poorly defined and is not delineated by geomorphic features indicative of latest Pleistocene to Holocene displacement (Figures 2b, 3b). Mapping by Brogan (1979) and McKee and Nelson (1967) was not verified by this writer, based on air photo interpretation. Field checking verified that a significant fault zone consisting of both vertical and moderately dipping shears exists in Mesozoic and Paleozoic bedrock, but geomorphic evidence of recency is generally lacking. Perhaps this is due in large part to the very rapid rate of erosion occurring in the Willow Wash area, coupled with what is probably a complex left-step in a right-lateral strike-slip fault zone. Therefore, it may be difficult to identify minor Holocene displacement along discontinuous strike-slip and reverse faults.

Traces of the NDVFC fault zone in the Cucomungo Canyon - Last Chance Canyon area are generally moderately to moderately well-defined and are delineated by geomorphic evidence of late Pleistocene to Holocene right-lateral strike-slip displacement, such as right-laterally deflected drainages, beheaded drainages, sidehill benches, linear ridges and scarps in late Pleistocene alluvium (Figure 3b). The minimum magnitude of late Cenozoic displacement is suggested by the approximately 5.3 km right-lateral displacement of Cucomungo Canyon (Figure 3b). Southeast of locality 8 (Figures 2b, 3b) the NDVFC fault zone is only moderately defined by geomorphic features that are more subdued and dissected.

Mapping by Brogan (1979) was generally verified by this writer, although differences in detail exist (Figures 2b, 3b). Specifically, the trace mapped by Brogan southeast of locality 26 (Figure 2b) is poorly defined and was not verified. Ponded, dissected older alluvium indicates late Quaternary displacement, but the principal active trace of the NDVFC fault zone seems to be stepping left to the northeast side of the dissected linear ridge in Tertiary sedimentary deposits (Figure 3b). Mapping by McKee (1985) and Moring (1986) was partly verified along the east side of the linear ridge (Figures 2b, 3b). The possibly offset Holocene alluvial deposit mapped by Moring (locality 10, Figure 2b) was not verified.

NORTHERN DEATH VALLEY

The NDVFC fault zone in the northern Death Valley region is characterized by a northwest-trending zone of right-lateral strike-slip faults (Figures 3c-3e). Well-defined geomorphic evidence of latest Pleistocene to Holocene right-slip displacement is common along much of the NDVFC fault zone in this region and includes right-laterally deflected drainages, right-laterally offset alluvial fan surfaces, and linear troughs and scarps in late Pleistocene and Holocene alluvium (Figures 3c-3e).

Traces of the NDVFC fault in the Last Chance Range quadrangle are poorly defined and are concealed by late (?) Holocene alluvium of Oriental Wash (Figure 3c). The general location of the fault can be inferred, based on the alignment of the linear ridge in Tertiary sediments, Sand Spring, Little Sand Spring, and very short scarps in latest Pleistocene alluvium mapped by Moring (1986) and verified by this writer (locality 11, Figures 2c, 3c). Minor normal faults in a broad north-northwest trending zone northeast of the NDVFC fault zone (located in both the Last Chance Range and Ubehebe Crater quadrangles) are generally moderately to poorly defined and faults mapped by Brogan (1979) and Moring (1986) were only locally verified (Figures 2c and 3c). These faults locally offset late Pleistocene alluvium, but Holocene alluvium is not offset and none of these minor normal faults have geomorphic evidence of Holocene displacement (Figures 2c and 3c). The short fault mapped by Moring (1986) as offsetting Holocene alluvium at locality 12 (Figure 2c) was partly verified. The scarp in late Pleistocene alluvium is subdued and dissected, but Holocene alluvium is not offset.

The principal trace of the NDVFC fault zone in the Ubehebe Crater quadrangle is generally well-defined and is delineated by geomorphic evidence of latest Pleistocene to Holocene right-lateral strike-slip displacement, such as right-laterally deflected drainages, sidehill benches, ponded alluvium, and scarps in latest Pleistocene and Holocene alluvium (Figure 3c). The statement by Moring (1986) that there is no evidence for Holocene displacement along the NDVFC fault zone is incorrect. Moring's Qf2c alluvial fan unit is probably early Holocene in age. Several alluvial fan surfaces offset by the NDVFC fault zone are characterized by slight to moderate desert pavement, well-preserved bar and channel constructional surfaces, slight to moderate rock varnish, and very little soil development. Similar fan surfaces on the northwest side of Silver Lake in the northeastern Mojave Desert (8 km north of Baker) were considered to be early

Holocene (8 ka to 10.5 ka), based on stratigraphic relationships with radiocarbon-dated shoreline deposits (Wells and others, 1985).

Traces of the NDVFC fault zone mapped by Brogan (1979) and Moring (1986) were generally verified by this writer, although considerable differences in detail exist (Figures 2c, 3c). Traces of the Death Valley Wash fault mapped by Brogan were not verified (Figure 2c). The faults are generally poorly defined and are largely modified by erosion.

The NDVFC fault zone in the Tin Mountain and Grapevine Peak quadrangles is generally well-defined and is delineated by geomorphic evidence of Holocene right-lateral strike-slip displacement such as right-laterally deflected drainages, linear troughs and ridges, sidehill benches, beheaded drainages, ponded alluvium, and linear scarps in latest Pleistocene and Holocene alluvium (Figure 3d). Linear vegetation contrasts were mapped in late Holocene alluvial fans just northwest and southeast of the Grapevine Ranger Station and a linear scarp in Holocene alluvium was mapped at the National Park Service residence area (locality 27, Figure 3d).

Faults mapped by Brogan (1979) and Reynolds (1969) along the NDVFC fault zone were generally verified by this writer (Figures 2d, 3d). Brogan (1979) mapped very subtle east-facing scarps and right-laterally deflected drainages in a Holocene alluvial fan at locality 28 (Figures 2d, 3d) that was only partly verified by this writer, based on air photo interpretation. A broad linear contrast across this fan coincides with the faults mapped by Brogan. The 15 cm high scarplet reported by Brogan is too small to be observable on the U.S. Geological Survey air photos used in this study. The principal trace of the NDVFC fault zone mapped by this writer south of locality 13 (Figures 2d, 3d) is located about halfway between faults mapped by Brogan (1979) and Reynolds (1969). The lack of adequate topographic control in the northern Mesquite Flat area suggests that the difference in mapping is due to plotting errors. Faults mapped by this writer are plotted with a Bausch and Lomb Zoom Transfer Scope and are believed to be accurate.

The southern end of the Death Valley Wash fault mapped by Brogan (1979) was not verified by this writer (Figure 2d). Fault traces generally are poorly defined and lack geomorphic evidence of latest Pleistocene to Holocene displacement.

An approximately 3 km long zone of extensional faulting is located east of the NDVFC fault zone and trends southeast from sec. 34, T11S, R43E (Figure 3d). Faults in this zone are delineated by moderately to moderately well-defined geomorphic features such as faceted spurs, scarps in Quaternary sedimentary deposits, and, locally, ponded alluvium (Figure 3d). Scarps in late Pleistocene alluvium generally are dissected and subdued. Evidence of Holocene displacement is generally lacking or weak, although a vague tonal lineament in Holocene alluvium indicates that minor Holocene displacement cannot be ruled out.

The NDVFC fault zone in the Stovepipe Wells quadrangle is generally well-defined in the northern and southeastern parts of the quadrangle and is delineated by geomorphic evidence of latest Pleistocene and Holocene right-

lateral strike-slip displacement, such as linear scarps in Holocene alluvium, right-laterally deflected drainages, and sharp groundwater barriers in Holocene alluvium (Figure 3e). The fault zone in the central part of the Stovepipe Wells quadrangle (sec. 3 and 11, T15S, R45E) is moderately defined by geomorphic features in Tertiary sediments, such as linear ridges, saddles and aligned notches, and right-laterally deflected drainages (Figure 3e).

Traces of the NDVFC fault zone in the Stovepipe Wells quadrangle mapped by Hunt and Mabey (1966) locally were verified by this writer, but almost all of the NDVFC was mapped as concealed by Hunt and Mabey (Figure 2e).

Traces of the NDVFC fault zone mapped by Brogan (1979) were generally verified by this writer, although significant differences in detail exist (Figures 2e, 3e). The principal traces of the NDVFC fault zone mapped by Brogan in the Mesquite Flat area east of Death Valley Wash, an area of poor topographic control, seem to be mislocated (locality 29, Figures 2e, 3e). The pattern of faults mapped by Brogan and this writer is similar, but Brogan's traces are located to the east (Figures 2e, 3e).

Locally, branch faults northeast of the principal trace of the NDVFC fault zone mapped by Brogan (1979) were verified by this writer (secs. 19, 28, 29, 33, T14S, R24E) although considerable differences exist (Figures 2e, 3e). These normal, somewhat arcuate faults offset late Pleistocene alluvium, but many are only moderately defined and do not have evidence of latest Pleistocene to Holocene displacement, especially those mapped by Brogan in sec. 33, T14S, R45E (Figures 2e and 3e).

The NDVFC fault zone in the Chloride Cliff quadrangle is locally well-defined and offsets Holocene alluvial fan and playa deposits (Figure 3e). However, significant reaches of the NDVFC fault zone are concealed by Holocene alluvium and the location of the principal active traces are indicated by dissected scarps or truncated ridges in late Pleistocene alluvium and linear tonal contrasts in Holocene alluvium (Figure 3e). The style of displacement along the NDVFC fault zone changes from predominantly right-slip to predominantly normal just north of Salt Springs (Figures 2e and 3e). The normal faults at the southern end of the Chloride Cliff quadrangle are moderately well to well-defined and offset latest Pleistocene and Holocene alluvium and playa deposits (down to the west) (Figure 3e).

Traces of the NDVFC fault zone mapped by Brogan were generally verified by this writer, although slight differences in detail exist (Figures 2e and 3e).

Faults mapped by Hunt and Mabey (1966) were generally not verified by this writer except locally in the western half of sec. 28, T28N, R1E (Figures 2e and 3e). The faults in alluvium in the southern half of sec. 33, T28N, R1E near the Park Service headquarters road were not verified and the north-trending fault mapped as offsetting Holocene alluvium in sec. 14 and 23 was not verified (Figure 2e).

SEISMICITY

Seismicity in the Fish Lake Valley - Northern Death Valley study area is depicted in Figure 6. Seismicity clustered on the western side of Fish Lake Valley in Nevada is probably associated with the NDVFC fault zone (Figure 6). Additional, isolated epicenters occur near the NDVFC fault zone northwest of the 37° latitude. These events may be associated with the NDVFC fault zone, but well-defined zones of microseismicity do not exist. South of 37° latitude the NDVFC is seismically quiescent.

CONCLUSIONS

The NDVFC fault zone in the Fish Lake Valley - Northern Death Valley study area is a major northwest-trending, predominantly right-lateral strike-slip fault zone (Figures 1, 2a-2e, 3a-3e). Cumulative strike-slip displacement along the NDVFC fault zone may be as much as 100 km (Stewart, 1983). Late Quaternary slip-rates along the NDVFC fault zone have not previously been reported, although a crude estimate, based on this FER, suggests a slip rate of about 2 mm/yr.

FISH LAKE VALLEY

The NDVFC fault zone in the Fish Lake Valley area is characterized by right-oblique-slip displacement (normal). Traces of the NDVFC fault zone offset latest Pleistocene and Holocene alluvium and generally are delineated by moderately well to well-defined geomorphic features indicative of latest Pleistocene and Holocene displacement (Figures 3a, 3b). Faults mapped by Brogan (1979) generally are well-defined and were verified by this writer, based on air photo interpretation and field checking (Figures 2a-2b, 3a-3b). Trenches excavated across well-defined tonal lineaments in Holocene alluvium in southern Fish Lake Valley mapped by Brogan were equivocal with respect to demonstrating faulting (Figures 2b, 3b, 4 and 5). Holocene deposits were offset in trench T-3 (Figure 4), but no obvious displacements were reported in trench T-4, although numerous fractures in Holocene deposits were observed (T. Sawyer, p.c., April 1988) (Figure 5). Brogan (1979) reported that some of these tonal lineaments may be artificial, but concluded that most these features delineated late Holocene faulting, based on the overall trend of the lineaments and their association with well-defined faults to the northwest (i.e. localities 23 and 24, Figure 3b).

WILLOW WASH - LAST CHANCE CANYON

The change in trend of the NDVFC fault zone through the Willow Wash area delineates a large left step in the fault zone that is probably characterized by a significant compressional component of displacement and a distributive style of displacement (Figures 2b, 3b). Faults in the Willow Wash area mapped by Brogan (1979) are discontinuous and distributive (Figure 2b). This zone of faulting is poorly defined and was not verified by this

writer (Figures 2b, 3b). However, the Willow Wash and Cucomungo Canyon areas are rapidly eroding and minor Holocene faulting within a distributive zone cannot be ruled out.

Faults in the Cucomungo Canyon - Last Chance Canyon area generally are moderately to well-defined and are delineated by geomorphic evidence of late Pleistocene and possible Holocene right-lateral strike-slip displacement (Figures 2b, 3b). Brogan (1979) reported that a terrace offset along the NDVFC fault zone south of Willow Spring is probably Holocene (Figure 2b). Traces of the NDVFC fault mapped by Brogan (1979) in the Cucomungo Canyon area were generally verified by this writer, but Brogan's western trace southeast of locality 21 could not be verified (Figure 2b). The NDVFC fault zone southeast of localities 3 (Figure 3b) and 8 (Figure 2b) is moderately defined in Tertiary sedimentary deposits and traces mapped by McKee (1985) and Moring (1986) were only locally verified by this writer (Figures 2b, 3b).

NORTHERN DEATH VALLEY

The NDVFC fault zone in Northern Death Valley is generally delineated by well-defined geomorphic evidence of latest Pleistocene and Holocene right-lateral strike-slip displacement (Figures 3c-3e). Traces of the NDVFC fault zone in the southern Last Chance Canyon - Oriental Wash area are poorly defined or concealed by late Holocene alluvium (Figures 2c and 3c). Minor normal faults located northeast of the NDVFC fault zone mapped by Brogan (1979) and Moring (1986) are moderately well-defined to poorly defined and lack geomorphic evidence of Holocene displacement (Figures 2c and 3c).

Faults mapped by Brogan (1979) along the NDVFC fault zone predominantly were verified by this writer and have abundant geomorphic evidence of latest Pleistocene and Holocene right-lateral strike-slip faulting (Figures 2c-2e, 3c-3e). Geomorphic surfaces offset along the NDVFC fault zone were interpreted to range in age from late Pleistocene to late Holocene (Brogan, 1979). Late Holocene surfaces are offset in the very southern part of the study area where the NDVFC fault zone is characterized by predominantly normal displacement (Figures 2e, 3e).

Moring (1986) concluded that evidence of Holocene displacement along traces of the NDVFC fault zone was lacking in the Last Chance Range and Ubehebe Crater 15-minute quadrangles (Figure 2c). However, alluvial fan units considered by Moring to be late Pleistocene are probably early Holocene, based on the similarities of surface morphology, soil development, desert pavement, and rock varnish to alluvial fans on the northwest side of Silver Lake reported as Holocene (8 ka to 10.5 ka) by Wells and others (1985).

Traces of the Death Valley Wash fault mapped by Brogan (1979) west of the principal trace of the NDVFC fault zone are generally poorly defined and lack geomorphic evidence of latest Pleistocene to Holocene displacement (Figures 3c and 3d).

The northwest-trending zone of extensional faults east of the NDVFC fault zone in the Tin Mountain 15-minute quadrangle is moderately to moderately well-defined and is delineated by geomorphic evidence of late Quaternary faulting (Figure 3d). Although minor Holocene displacement cannot be ruled out, based on a weak tonal lineament in Holocene alluvium, the generally dissected scarps in late Pleistocene alluvium indicate a low rate of activity along the fault. Additionally, the northwest-trending fault zone, located up to 3 km east of the NDVFC fault zone, is in a relatively remote and inaccessible area and is not considered to be a zonable feature.

RECOMMENDATIONS

Recommendations for zoning faults for special studies are based on the criteria of "sufficiently active" and "well defined" (Hart, 1985).

FISH LAKE VALLEY

Zone for special studies well-defined traces of the NDVFC fault zone mapped by Brogan (1979) and Bryant (this report) as depicted in Figures 2a 2b, 3a, and 3b (highlighted in yellow). Principal references cited should be Brogan (1979), Krauskopf (1971), Stewart and others (1974), McKee and Nelson (1967), and Bryant (this report).

WILLOW WASH - LAST CHANCE CANYON

Zone for special studies well-defined traces of the NDVFC fault zone mapped by Brogan (1979) and Bryant (this report) as depicted in Figures 2b and 3b (highlighted in yellow). Principal references cited should be Brogan (1979), McKee (1985), and Bryant (this report).

NORTHERN DEATH VALLEY

Zone for special studies well-defined traces of the NDVFC fault zone mapped by Brogan (1979) and Bryant (this report) as depicted in Figures 2c-2e and 3c-3e (highlighted in yellow). Principal references cited should be Brogan (1979), Moring (1986), Reynolds (1969), Hunt and Mabey (1966), and Bryant (this report).

Reviewed; recommendations approved.
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7/8/88

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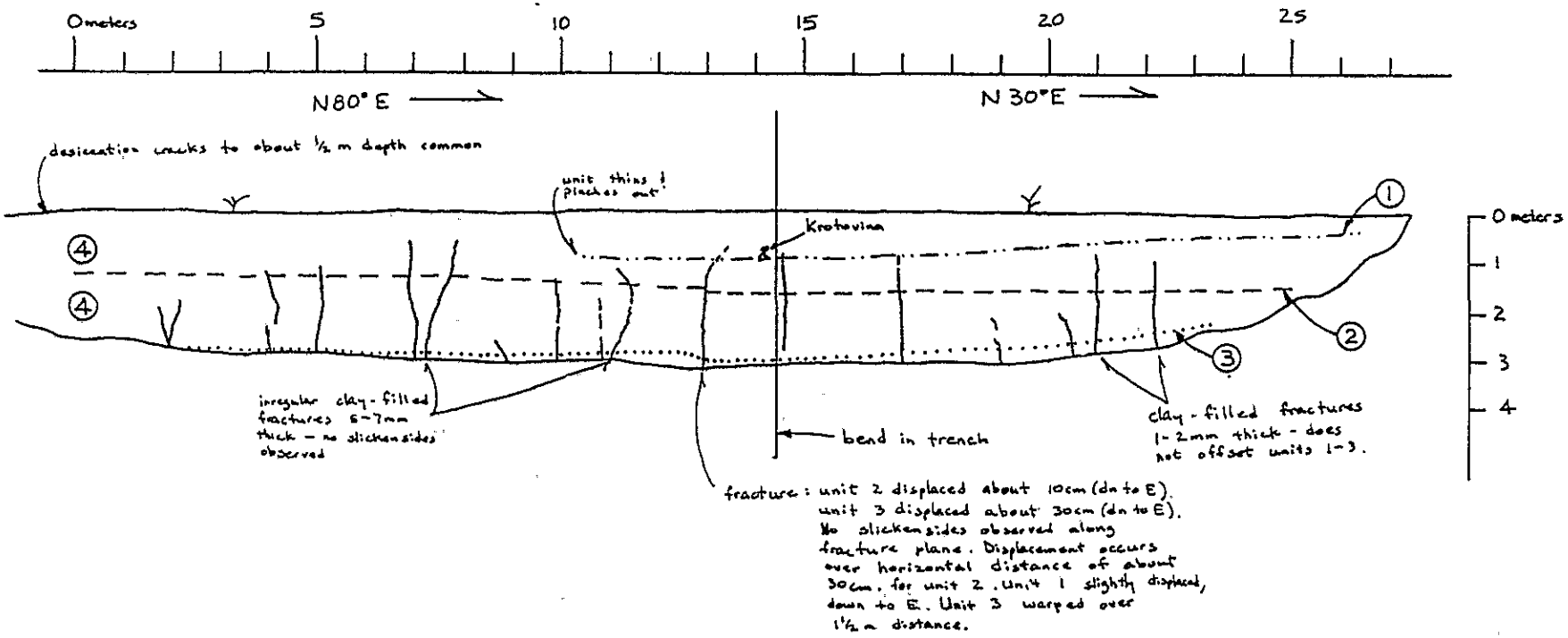
TABLE 1

ESTIMATED AGES OF GEOMORPHIC SURFACES
(FROM BROGAN, 1979)

Surface	Estimated Age	
Q1A	0-200 years	Historic
Q1B	200-2000 years	Late Holocene
Q1C	2000-10,000	Holocene
Q2	>10,000	Pleistocene



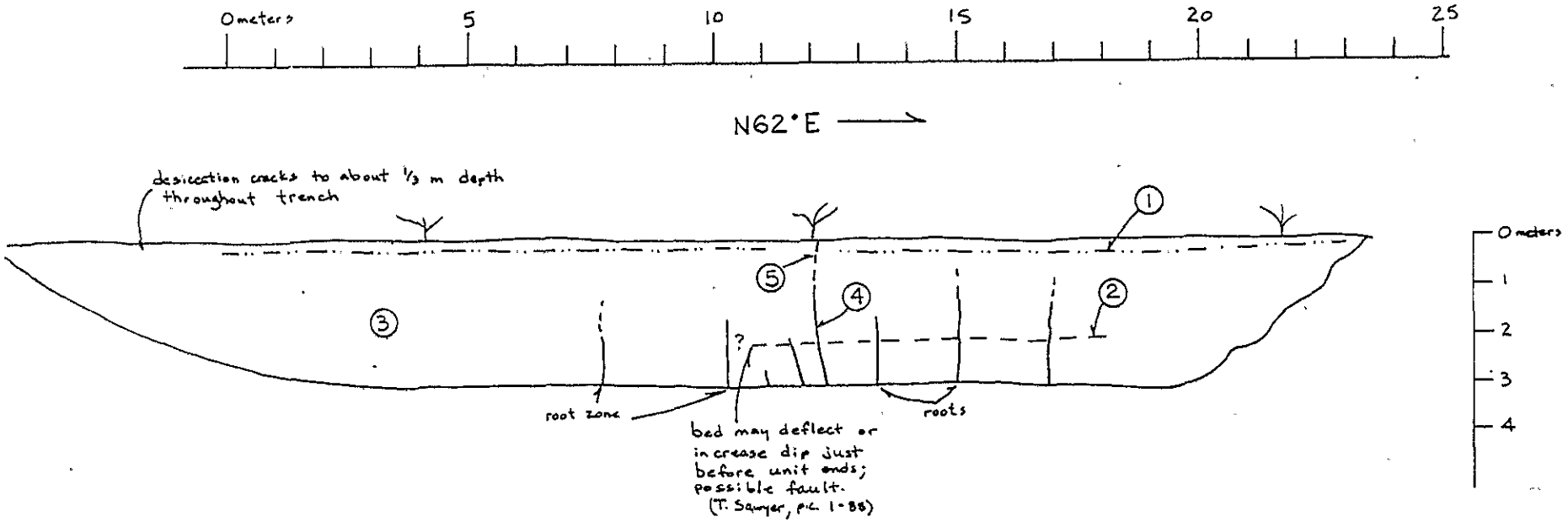
① Silt, light brownish gray (2.5YR 6/2 D), laminated, about 5cm thick.

② Fine to medium-grained sand, massive, about 5cm thick.

③ Medium-grained sand, 7 to 10cm thick, massive, contacts often irregular and wavy.

④ Sand silt to silty very fine sand, very pale brown (10YR 7/3 D), relatively massive and stuctureless.

Figure 4 (to FER-193). North wall of trench T-3 across eastern trace of NDVFC fault zone at locality 7 (Figure 2b) excavated by T. Sawyer, University of Nevada, Reno. Sketch by Bryant (this report).



(1) Distinct, laminated silt bed, light gray (10YR 7/2 D), about 7½cm thick, grades to laminated sand at W end of trench- partly eolian (?).

(2) Thin (≈2½cm), massive to laminated very fine sand bed, not displaced across fractures.

(3) Massive very fine silty sand, very pale brown (10YR 7/3 D), locally laminated clay, but generally structureless- playa deposits.

(4) Fracture- roots along fracture plane to bottom of trench. No shearing, slickensides, or striations observed. Some clay-filled root casts. No clear evidence of displaced beds.

(5) Unit 1 cannot be traced across fracture- disturbed zone probably due to growth of vegetation.

Figure 5 (to FER-193). North wall of trench T-4 across eastern trace of NDVFC fault zone at locality 6 (Figure 2b) excavated by T. Sawyer, University of Nevada, Reno. Sketch by Bryant (this report).